The ASM Report System

Advancements in the Fabrication Technology of Titanium for the C-5A

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Presented at the 1968 Materials
Engineering Exposition & Congress
14-17 October 1968
Detroit, Michigan

AMERICAN SOCIETY FOR METALS
METALS PARK, OHIO

TECHNICAL REPORT NO. D 8-26.2

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ADVANCEMENTS IN THE FABRICATION TECHNOLOGY OF TITANIUM FOR THE C-5A

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Titanium applications on the C-5A aircraft and fabrication technology advancements which evolved from these usage items are presented. The primary reason for selecting titanium in lieu of aluminum or steel for C-5A applications was to reduce weight of aircraft structural components.

The author is associated with Lockheed-Georgia Company, Marietta, Georgia. This paper is scheduled for the ASM Materials Engineering Congress at Detroit, Michigan, October 17, 1968.

ABSTRACT

The application of titanium for aircraft structural and functional components on the C-5A consists of sheet, plate, forgings, extrusions, tubing, and ducting. Parts are made from commercially pure titanium and the following alloys: Ti-6Al-4V, Ti-6Al-6V-2Sn, Ti-8Al-1Mo-1V, Ti-5Al-2.5Sn, and Ti-3Al-2.5V. There are approximately 1.3 million titanium fasteners used on each C-5A out of a total usage of 2 million fasteners. Titanium fasteners are made of Ti-6Al-4V, Ti-6Al-6V-2Sn, and Ti-1Al-8V-5Fe alloys and consist of tapered interference fasteners as well as straight shank fasteners.

Titanium fabrication technology advancements in hot forming, chemical milling, machining, and welding were made as a result of studies performed on potential applications of titanium for the C-5A. Data on forgings and extrusions was developed and costing methodology was established during studies performed on potential applications and for final components selected to be made of titanium on the C-5A.

The primary reason for selecting titanium in lieu of aluminum or steel for C-5A applications was to reduce weight of aircraft structural components. Titanium shows a weight saving advantage over aluminum for parts subject to high load density in tension, and over steel for parts which are subject to either tension or compression loading, for steel strength levels to the 260 - 280 ksi Ftu range. → p. 4

INTRODUCTION

The potential advantages of the use of titanium in a large transport type aircraft to reduce airframe structural weight and provide the Air Force with an extremely long range logistics aircraft was studied early in the C-5 program. A comprehensive materials selection evaluation and trade-off study program was made during the initial phases of the C-5 program. This work consisted of titanium materials selection and Value Engineering considerations, as well as structural data considerations in the selection of titanium in lieu of aluminum, steel, or other candidate materials. It was necessary to conduct investigative programs for development of titanium material processing, fabrication, and assembly data, design allowables, fasteners, and tubing and hydraulic fittings.

DISCUSSION

The use of titanium alloys in lieu of aluminum or steel is a most promising way to reduce weight of aircraft structural components through material selection. Titanium shows an advantage over aluminum for parts which are subject to high load density in tension. It shows an advantage over steel for parts which are subject to either tension or compression loading, for steel strength levels up to the 260 - 280 ksi Ftu range.

To keep C-5 fabrication costs within reason for titanium structures and to assure that the producibility of components to be fabricated are such that desired production rates could be met, a detailed study was undertaken to select structural and functional components best suited for the use of titanium. Titanium was recommended in areas which would

simultaneously provide:

- o The greatest weight reduction at the least additional cost.
- o The greatest probability of success in manufacture.
- o The least impact on facilities, tooling, and equipment requirements.

These are goals which may not always be achieved. Attainment of these goals is attempted by proper selection of the raw material forms and fabrication methods used. Generally, the following raw material forms and fabrication methods, in order of increasing cost, or decreasing producibility, are those which meet these goals.

Titanium Sheet - Titanium sheet should be used:

(a) flat, where only drilling or trimming is required.

(b) single contoured, which can be formed by rolling, where only drilling or trimming is required.

(c) in a progressive compressive roll formed cross-section which requires little or no contour forming.

(d) in applications where room temperature forming methods, followed by stress relieving, are adequate.

Titanium Extrusions - Titanium extrusions should be used:

(a) straight, where only drilling, trimming, and/or cut-out machining is necessary.

(b) in applications where room temperature forming methods, followed by stress relieving, are acceptable.

(c) in applications where chemical-milling will produce the required cross-section.

(d) net, that is, without machining all over.

Titanium Forgings - Titanium forgings should be used:

(a) in lieu of steel forgings that are to be heat treated up through the 260 - 280 ksi Ftu range. For tubular forgings that are stiffness critical weight savings are possible over steel forgings even in the 280 - 300 ksi range.

(b) with as many as-forged and pickled surfaces as possible so that machining costs are reduced.

These goals are not always attainable for the various shapes required in detail design, and although desirable it became apparent that most extrusions would require over-all machining and elevated temperature (1000 - 1400°F) forming for C-5 applications.

In a preliminary study for using various amounts of titanium structure on the C-5 airframe it was shown that a structural weight reduction of 5,000 pounds could be achieved by the integration of approximately 20,000 pounds of titanium into the structure. Additional studies showed that a total of 10,000 pounds could be saved by the use of 60,000 pounds of titanium structure. It can readily be seen that the second 5,000 pound weight saving requires twice as much titanium as the first. This is due to the approach taken of utilizing titanium in its simplest form, in the simplest applications first. Conversely, the second 5,000 pounds of weight saved increases the complexity of material form and fabrication methods. These figures from preliminary studies were actually pessimistic as the actual usage of titanium in the C-5 of 7,767 pounds for structural applications achieved a weight reduction of

4,064 pounds. This represents optimum usage items for titanium where the cost per pound saved ranges from $11 to $185. Alloys used and material form are shown in Table I.

Some typical examples of these applications are shown in Figures 1 through 5. Figure 1 shows Ti-6Al-4V STA splice plates used on aluminum main frames; Figure 2 shows Ti-6Al-4V annealed fail-safe straps adhesively bonded to aluminum skin material; Figure 3 shows the fail-safe straps in underfloor skin applications; Figure 4 shows the chine web longeron made of Ti-6Al-4V STA sheet; and Figure 5 shows underfloor bulkhead beam caps made of Ti-6Al-4V STA plate.

Emphasis was placed on selecting titanium alloys for C-5A component applications which exhibit the best system effectiveness. Primary considerations in the selection of alloys include fatigue life, corrosion resistance, fracture tolerance, static strength, stiffness, thermal expansion, minimum gage, producibility, maintainability, inspectibility, performance, and availability.

The evaluation of potential applications for titanium was based upon the following detailed activities:

- Structural weight breakdown by major sections, subsections, and individual structural elements.
- Stress analysis for the purpose of sizing structurally equivalent elements in the appropriate titanium alloy.
- Optimization of the structural design to take advantage of the material's properties.
- Producibility analysis for the selection of the most appropriate form of material for each application considering the manufacturing complexities, tooling, material, and facility costs.
- Value engineering studies to establish the functional worth and the cost differential between titanium and the replaced aluminum and steel parts.
- Facility studies to establish the full impact on facilities resulting from titanium usage.
- Performance analysis to compute the changes in fuel requirements, operating weight and take-off gross weights resulting from structural weight decreases.
- Performance of operations analysis for deriving the operating cost of a fleet of aircraft over a 10-year period.

The methodology used for developing titanium production costs was to compare the relative difficulty of manufacturing titanium to that of aluminum on an elemental operational basis. Comparative data were obtained from such sources as (1) Materials Laboratory, WPAFB, "A Survey of the Comparative Costs of Fabricating Airframe from Aluminum and from Titanium," (2) studies by Lockheed in connection with the SST proposal, and (3) factors presented by titanium industry representatives reporting on their experiences with fabricators of titanium.

This correlation culminated in establishing appropriate complexity factors for various fuselage structural components such as skins, rings, stringers, and longerons. These factors were applied to the costs of aluminum or steel construction to derive the cost of equivalent titanium construction. These complexity factors are shown in Table 2.

Similar factors were established for structural elements in the wing, empennage, pylons, nacelles, and landing gear.

Titanium Fasteners - Tapered and Straight Shank. The extensive usage of interference fit tapered titanium alloy fasteners on the C-5A aircraft represents a significant aircraft structural design advancement. The interference fit tapered fastener design concept provides added fatigue life to aluminum structure permitting thinner gage aluminum fuselage skins, and other structural members to perform with equivalent fatigue life to much heavier structural designs. This structural weight saving advantage can be accomplished with either steel or titanium tapered fasteners, but the use of titanium offers additional weight savings.

These tapered fasteners have a slightly tapered shank (.021 inches per inch) and are finished to very close tolerances. Most of the tapered fasteners on the C-5A aircraft are made of Ti-6Al-4V, STA condition, with a smaller number made of Ti-1Al-8V-5Fe, STA condition. In addition, there are some straight shank fasteners made of Ti-6Al-6V-2Sn, STA condition. These straight shank fasteners are used to attach forgings and extrusions where the interference fit fastener is prohibited because it would increase susceptibility to stress corrosion cracking.

There are 2,206,400 fasteners used on the C-5A aircraft, of which the titanium fasteners total is 1,470,000 or 65% of the total. These are divided as follows:

Ti-6-4	Low Profile Taper-Loks	863,000
Ti-6-6-2	Hi-Loks (Straight shank)	500,000
Ti-1-8-5	Taper-Loks	107,000
Ti-13-11-3	Lockbolts	40,000

M. Forbes
Feb 19, 1970

Weight savings on the C-5A aircraft of 9,770 pounds is realized by the use of titanium fasteners. This is itemized below:

2,180 pounds lighter than aluminum and steel fasteners
7,590 pounds lighter due to structural effects and edge distance advantages

The weight saving advantages shown in Table 3 are explained as follows:

1. The titanium fasteners can be used in many instances at a smaller diameter than the lower strength aluminum counterpart. The smaller diameter fastener and the lighter weight of titanium as compared to its counterpart in steel results in a weight saving of 22% of the 9,770 pounds due to the difference in fastener weights, and a weight savings of 3% of the 8,210 pounds due to decreased edge distance.

2. The effect of an interference fit fastener in aluminum fuselage pressure skins permits the structure to be stressed to 18 ksi compared to 14 ksi as on the C-141 aircraft with equivalent or better fatigue life. This results in thinner gage fuselage skins for a substantial weight savings. Wing cover ultimate stresses approaching Ftu are permitted due in part to use of interference fit tapered fasteners. Previous designs were limited to wing cover stresses of 50 ksi. Items such as these provide the major weight saving contribution of 75% of the 9,770 pounds due to the structural efficiency improvement realized.

Copy Tables 1, 3, & 4

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A breakdown of fasteners used on the C-5A is summarized in Table 4.

CONCLUSIONS

Titanium technology at Gelac has made giant steps forward from 1964 through 1968. This is also true for the basic mill production facilities; advanced technology at other major aerospace companies; and throughout the subcontractor aerospace companies which provide supporting processing, fabrication, and manufacturing facilities. A great impetus for this widespread industry technology advancement has been the need for additional data required for C-5A and SST design and production data.

Significant developments have been made at Gelac in titanium manufacturing technology. One of these is in tooling concepts for elevated temperature forming of titanium with ceramic dies, and ceramic heating chambers with enclosed nickel base alloy tooling. Forming pressures are supplied by a modified hydraulically operated brake press. Titanium welding technology advancements for fabrication of built-up structures and welding of tubing for hydraulic systems has been accomplished.

Basic mill production capability has been doubled over the past three years with new facilities added to produce sheet and strip with improved surface finish, and a new facility capable of producing annealed sheet-strip to close tolerance and long lengths.

Developments in titanium extrusion production have made large wide panel integrally stiffened extrusions available on a developmental basis. This development work is in progress under an Air Force funded program which is managed by Lockheed with the extrusions being made by Curtiss-Wright. Studies indicate that these large extrusions can be made into wing box structure for large aircraft which will be lighter weight and provide better cost effectiveness than current aluminum designs.

The H. M. Harper Company is now quoting on production of light gage "net" titanium extrusions.

Current work with titanium castings is very promising, but additional work is required to provide design allowables data before they can be utilized in airframe structures.

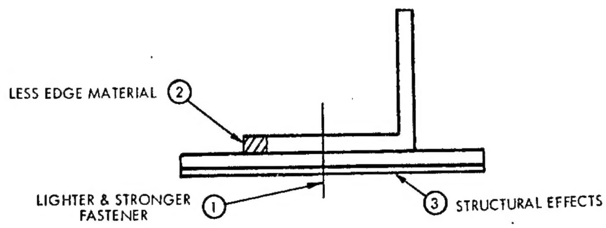
Table 1. Titanium Usage on C-5A Compared to C-130 and C-141 Usage

C-130	300 lbs. (C.P. Sheet)	
C-141	600 lbs. (C.P. & 6-4, S. & P.)	
C-5		
C.P. Sheet		691 lbs.
6-4 Sheet		2258 lbs.
6-4 Plate		838 lbs.
6-4 Extrusion		2460 lbs.
6-4 Forging		142 lbs.
6-4 Bar		42 lbs.
6-6-2 Forging		290 lbs.
8-1-1 Extrusion		452 lbs.
8-1-1 Sheet		52 lbs.
3-2.5 Tubing		542 lbs.
		7767 lbs.

Table 2. Complexity Factors for Titanium Fuselage Structures (As Compared to Aluminum at 1.0)

Component	Fabrication Complexity Factors	Assembly Complexity Factors
R. T. Roll Formed Skins	0.53	1.40
Hot Formed Skins	1.32	1.55
Comp. Roll Formed Shapes	1.35	1.30
Main Frames	2.40	1.50
Stretched Wrapped Extr. (All Surfaces Machined)	3.42	1.30
Straight Extrusions (All Surfaces Machined)	3.39	1.90
Floor Panels	1.60	1.50

Table 3. Weight Saving On C-5A Structure Due to Fastener System Used



TOTAL C-5A STRUCTURAL WEIGHT IS 247,727 LBS.

WEIGHT SAVINGS	WEIGHT SAVED	% OF WEIGHT SAVED
1. STATIC STRENGTH - TITANIUM FASTENERS	2,180	.9
2. REDUCED EDGE DISTANCES	300	.1
3. IMPROVED FATIGUE	7,290	2.9
TOTAL WEIGHT SAVINGS	9,770 LBS.	3.9%

Table 4. Fastener Summary for the C-5A

Material	Configuration: Straight	Configuration: Interference (Tapered)
Aluminum	690,000	————
Titanium	500,000	970,000
Steel	44,000	2,400
Total	1,234,000	972,000

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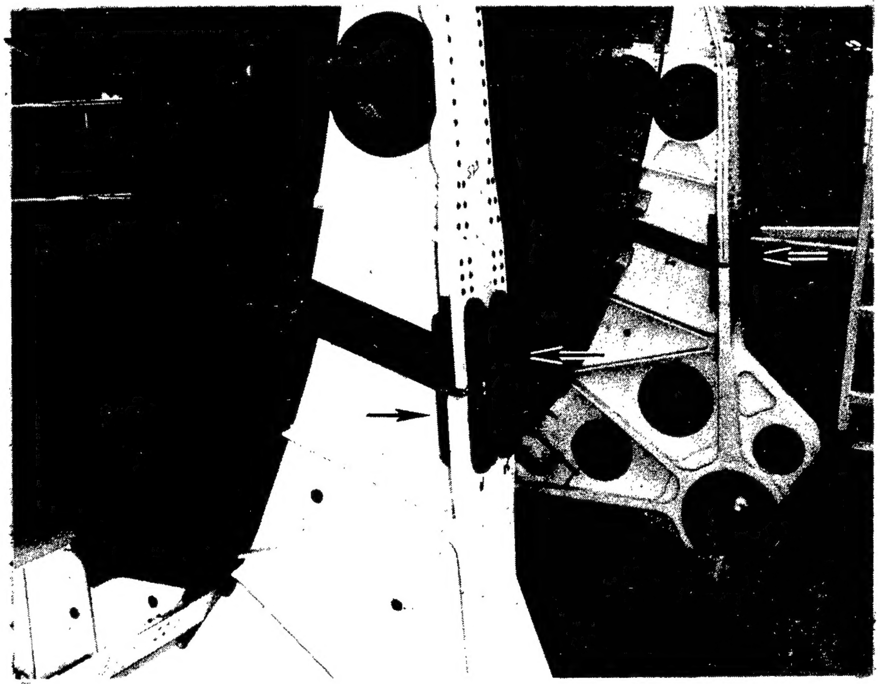

Fig.1. Titanium 6Al-4V STA splice plates, (see arrows) installed on aluminum main frames.

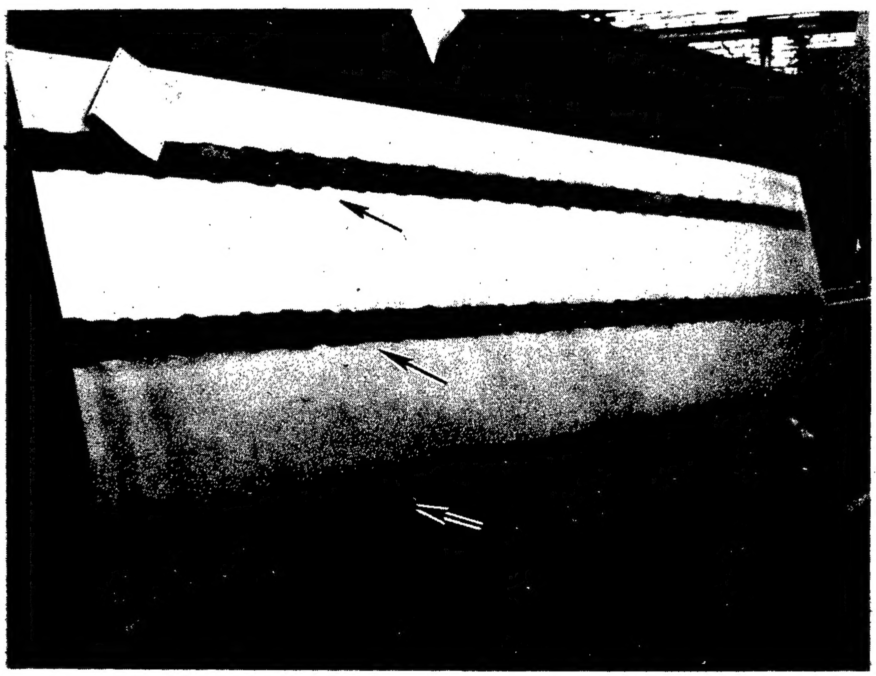

Fig. 2. Titanium 6Al-4V annealed fail safe straps bonded to aluminum skin prior to contour forming. (see arrows)

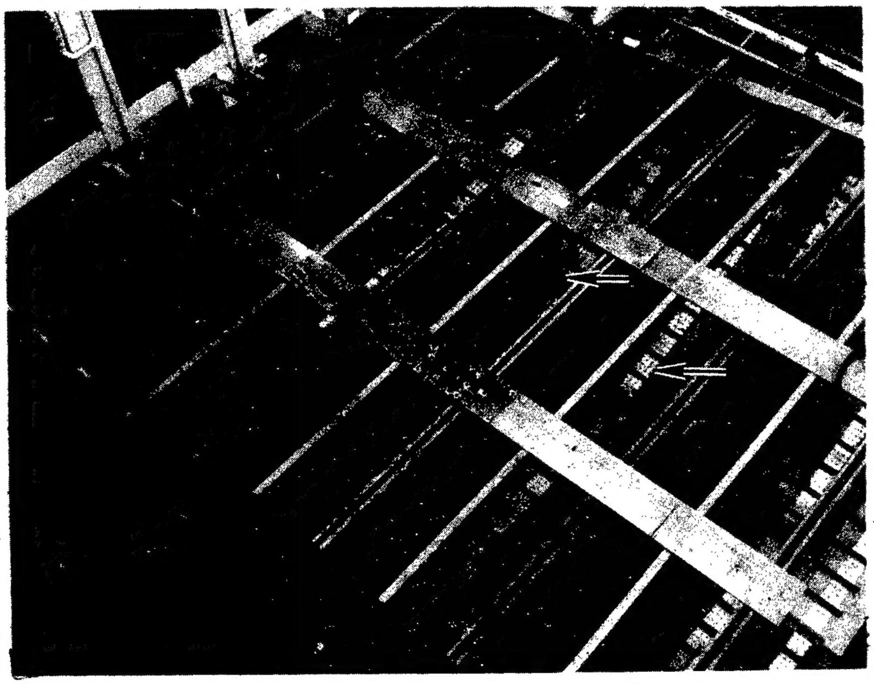

Fig. 3. Titanium 6Al-4V fail safe straps assembled in underfloor skin area. (see arrows)

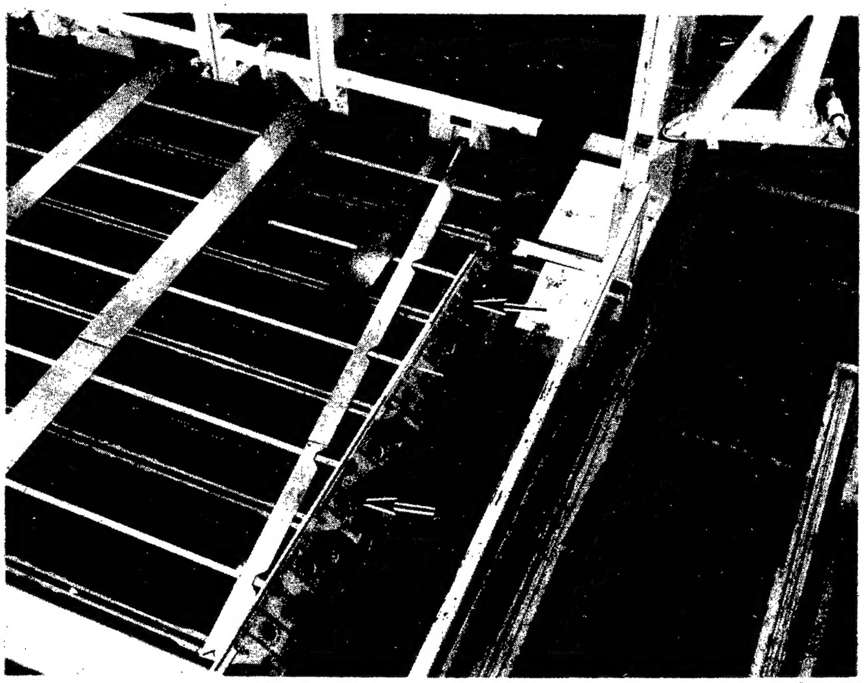

Fig. 4. Titanium 6Al-4V STA chine web longeron. (see arrows)

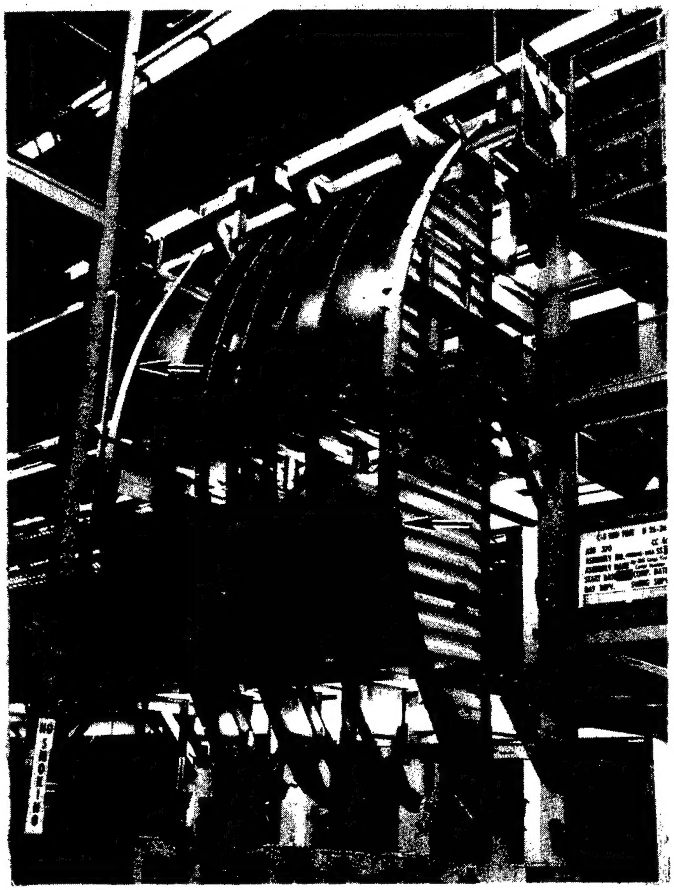

Fig. 5. Titanium 6Al-4V STA underfloor bulkhead beam caps. (see arrows)

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